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DOES THE PRESENCE OF A NON-COINCIDENT VISUAL SPATIAL PATTERN
FACILITATE SPATIAL PATTERN LEARNING?
IMPLICATIONS FOR A DEDICATED SPATIAL PATTERN LEARNING SYSTEM

by

SCOTT KATZ

(Under the Direction of Bradley R. Sturz)

ABSTRACT

Spatial pattern learning is defined as an ability to learn spatial relationships of objects in space without the use of discrete visual landmarks or environmental geometry (Brown & Terrinoni, 1996). Spatial pattern learning has been suggested to be a distinct form of learning because it is not affected by cue competition and has been shown to occur in the absence of discrete landmarks and environmental geometry (Brown, Yang, & DiGian, 2002; Sturz Brown, & Kelly, 2009). In the proposed study, the distinctness of spatial pattern learning was investigated. Specifically, human participants searched in an interactive 3-D computer generated virtual environment open-field search task for four unmarked goal locations which were arranged in a diamond configuration located in a 5 x 5 matrix of raised bins. The pattern moved to a random location from trial-to-trial but always maintained the same spatial relations to each other (i.e., diamond pattern).

Participants were randomly assigned to either a Visual Pattern group or a Visual Random group in which the visual stimuli (i.e., four red bins) were either arranged in a pattern consistent but not coincident with the unmarked goal locations (Visual Pattern group) or were randomly arranged in the virtual room (Visual Random group). If spatial pattern learning is processed by a distinct learning system that utilizes visual information, then the exposure to the structured visual cues (i.e., red bins) should facilitate spatial pattern

learning compared to exposure to random visual cues. Consequently, we found that participants in the Visual Pattern group performed significantly better than those in the Visual Random group. Collectively, results are consistent with an interpretation based upon a spatial learning system dedicated to processing visual pattern information.

INDEX WORDS: Spatial, Pattern learning, Virtual environment

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MASTER OF SCIENCE

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SCOTT KATZ

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DEDICATION

I would like to dedicate this book to my friends, and most importantly, my family.

Thank you for all of your support. I would not be who I am today without you.

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I would first like to thank Dr. Bradley Sturz for his support and direction over the past few years. You have always been there with great advice over the past few years and I can't begin to thank you enough for that. One couldn't ask for a better teacher/mentor. I would also like to thank Dr. Kent Bodily. You are a great teacher and mentor and have always pushed me to think critically. I greatly appreciate all of the advice and direction you have given during my time at GSU. I would also like to thank Dr. Lawrence Locker. Your guidance in both class and in my research has helped tremendously. Thank you all for everything. I would not have been able to accomplish this without your support.

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CHAPTER 1

INTRODUCTION

Living organisms are presented with many spatial challenges such as returning to a nest, food source, or water source. Spatial cues such as visual landmarks and environmental geometry have been suggested to be the environmental cues used to return to previously visited locations (for a review, see Brown, 2006). Visual landmarks are discrete objects that remain in a location within an environment (Shettleworth, 1998). In contrast, environmental geometry refers to the geometric properties of the environment, such as boundaries and corner angles (Shettleworth, 1998). Spatial learning involving visual landmarks entails the use of a discrete object in the environment to determine both location and orientation (Gallistel, 1990) whereas environmental geometry learning involves the use of geometric properties to determine both location and orientation (Cheng & Newcombe, 2005).

Several learning models, such as the unitary associative-based learning system and the dual process learning system have been suggested to be responsible for spatial learning (Burgess, 2006; Chamizo, 2003). The unitary associative-based learning model uses discrete landmarks to both orient and to locate goal locations within an environment. The dual process learning system uses both landmarks and environmental geometry to orient and locate goal locations within an environment.

Spatial learning has also been found in an environment in which discrete visual landmarks were not present in the environment and the environmental geometry was not congruent with the goal locations (Brown & Terrinoni, 1996). This type of spatial

learning was termed spatial pattern learning. A separate learning system from the unitary associative-based model and the dual process model has been suggested to be responsible for spatial pattern learning. This is due to several studies that suggest that this type of learning does not have the same restrictions as landmark learning and environmental geometry learning. Furthermore, several studies have suggested that this type of learning can also be enhanced by using visual landmarks (Brown, Yang, & DiGian, 2002; Sturz, Brown, & Kelly, 2009; Sturz, Kelly, & Brown, 2010).

Purpose of the Study

Given the previous research's findings on spatial pattern learning, it is necessary to further investigate if a learning system separate from the unitary associative-based system and the dual process learning system is responsible for spatial pattern learning. The current research assessed the distinctness of spatial pattern learning by investigating if the presence of a consistent (but not coincident) visual pattern can enhance spatial pattern learning. The paper begins with an overview of spatial learning, followed by a discussion of the current study.

CHAPTER 2

REVIEW OF PAST LITERATURE ON SPATIAL LEARNING

Landmark Learning

Many animals have been shown to use discrete visual landmarks to determine a goal location. For example, pigeons (Cheng, 1989), dogs (Fiset, 2007), and human children and adults (MacDonald, Spetch, Kelly, & Cheng, 2004; Sturz, Cooke, & Bodily, 2011a) appear to use discrete objects to locate a goal. Cheng and Sherry (1992) for example, conducted a series of experiments on chickadees and pigeons to examine if landmarks can be used to identify spatial locations. In these experiments, a landmark was paired with a goal location that contained a hidden food source. When the landmarks were shifted in a parallel fashion from their original location, the birds search shifted in the direction of the landmark (Cheng & Sherry, 1992). Cheng and Sherry (1992) suggested that these results showed that birds can use landmarks to find a spatial location. It has been suggested that that when using landmarks to identify a spatial location, mathematical representations of distance and direction information, in which length of a line segment represent distance and orientation in space represents direction, are used to relate the landmark to the spatial location (i.e., vectors)(Cheng, 1989).

Environmental Geometry Learning

Environmental geometry can also be used to locate and identify a spatial location. Spatial learning based on environmental geometry involves the encoding of geometric information (e.g., boundaries and corner angles within the environment) from one's environment and using that information to determine a position and orientation within the

environment (Shettleworth, 1996). More specifically, environmental geometry such as corner angles, boundaries, and other geometrical information from the environment can be used to orient within an environment. This geometric information is used in the same fashion that discrete visual landmarks are used to both orient and find a location, in that environmental geometry can be related to both oneself and/or a location to both determine orientation and distance (Cheng & Newcombe, 2005). Similar to discrete visual landmarks, many animals have been shown to use environmental shape to orient such as rats (Cheng, 1986), pigeons (Kelly, Spetch, & Heth, 1998) and humans (Sturz, Gurley, & Bodily, 2011b).

Cheng (1986), for example, conducted a series of experiments on rats in which both landmarks and environmental geometry were present. Rats were trained and tested in rectangular shaped environments in which all four walls were either black or 3 walls were black and one was white (Cheng, 1986). Each rat was disoriented prior to each trial and inserted into the environment at random directions. The corners in these environments were all distinct from each other with different visual patterns and odors. The rats in this experiment could use two types of cues, feature cues (i.e., visual patterns in the corners and odors) and geometric cues (i.e., wall length and corner angles). The corners were manipulated by removing features, shifting the features clockwise around the environment, and having the features in the corners mirror the geometric equivalent corner. The goal locations were moved randomly within the enclosure for each set of trials. This was done by familiarizing the rat with the goal corner, removing and disorienting the rat, and then placing the rat back in the environment to test if the rat can

find the goal location. Search at the correct goal would be evidence for feature cues and search at both the correct location and the rotational equivalent location would be evidence for geometric cues because both the correct location and the rotationally equivalent location have the same geometric properties. Cheng (1986) hypothesized that the rat's performance would decline when the properties that were used to specify a place (i.e., corner features and wall colors). They found that the rats made rotational errors on almost all trials and would only rely on feature cues when the geometric corner was ambiguous by moving the goal location. These results suggest that rats can use both feature and geometric cues to find a goal location. However, when presented with both feature and geometric cues, the rats relied more heavily on the geometric cues (Cheng, 1986).

The use of environmental geometry and discrete visual landmarks to learn spatial locations and to orient within an environment has been found to be susceptible to several Pavlovian phenomena, such as blocking and overshadowing (Chamizo, 2003; Miller & Shettleworth, 2007). Blocking refers to the phenomenon in which a previously learned relationship prevents the learning of a new relationship involving previously learned stimuli (Shettleworth, 1998). Therefore it is said that the previously learned relationship blocked the new relationship from being learned. Overshadowing, however, is when a compound stimulus (i.e., two stimuli paired together) is conditioned and elicits a conditioned response, but when the paired stimuli are tested alone, one elicits a stronger conditioned response than the other (Shettleworth, 1998). That is, one stimulus overshadowed the other, and therefore it can be inferred that more information was

learned about the specific stimulus that elicited the stronger conditioned response. The existence of blocking and overshadowing has been suggested as evidence for both the unitary associative-based learning system and the dual process learning system that is responsible for spatial learning (Chamizo, 2003). This is because these two spatial learning models take into account the use of environmental geometry and/or landmarks to orient and locate goals within an environment. Both of these cues have been shown to be susceptible to Pavlovian phenomena, and therefore it has been suggested that the occurrence of this Pavlovian phenomena is evidence for both the unitary associative-based learning system and the dual process learning system (Chamizo, 2003; Miller & Shettleworth, 2007).

Spatial Learning Models

A great deal of theoretical debate remains concerning how spatial information is processed. Unitary associative-based models suggest that the learning system that is responsible for spatial learning takes into account the relationship of all learned discrete landmarks (Chamizo, 2003). According to these models, landmarks can be used as points of reference to compute mathematical representations of distance or to simply find heading and orientation. Blocking and overshadowing have been used as evidence for a unitary associative-based spatial learning system as these phenomena have been found in spatial learning when involving discrete landmarks (Chamizo, Sterio, & Mackintosh, 1985).

Specifically, Chamizo et al. (1985) conducted a study in which Pavlovian phenomena were investigated in landmark learning. In this study, rats were tested in

three different experiments to determine if spatial learning using landmarks is susceptible to blocking and overshadowing. The authors hypothesized that if the rats used a cognitive map to find the goal locations, then blocking and overshadowing will not be observed. However, if blocking and overshadowing was observed, then some other form of learning must be responsible. The rats were tested in a radial arm maze, in which they were placed in the center of the maze for each trial. The heading of each rat was random from trial-to-trial. Sandpaper and rubber were used as the cues and were either placed within the maze (i.e., intra-maze cue) or outside the maze (i.e., extra-maze cue). Rats were pre-trained, trained, and tested with all intra-maze cues, all extra-maze cues, or a compound of both. The first two experiments tested for blocking and the third tested for overshadowing. Chamizo et al. (1985) found that the landmarks for the compound groups were blocked and overshadowed. Therefore, a learning system that was separate from the cognitive maps model was responsible for this landmark learning. However, these phenomena have also been found when spatial learning involves environmental geometry and the unitary associative-based learning system does not account for how animals can learn to orient and find locations within an environment while only using environmental geometry (Miller & Shettleworth, 2007).

In contrast, the dual process learning system suggests that a learning system responsible for spatial learning uses both landmarks and environmental geometry from both an allocentric and egocentric point of view (Burgess, 2006). According to Burgess (2006), animals view landmarks and environmental geometry from both an outside perspective (i.e., allocentric) and a personal perspective (i.e., egocentric). The allocentric

view uses representations of the relationships between the landmarks or the geometry to determine both orientation and location, whereas the egocentric view uses the animals own relationship with landmarks or geometry to determine both orientation and location (Burgess, 2006).

Waller and Hodgson (2006) also showed evidence for a dual process learning system in an experiment with human participants. In this experiment, participants were brought into a room that contained several objects randomly placed. The participants were asked to study where the objects were and then were asked to point at the objects via electronic pointing device. Participants went through several phases in which they were disoriented and either were blindfolded or not. In this experiment, the egocentric view would be the participant's own view of where all of the objects are located in reference to themselves, whereas the allocentric view would be a cognitive layout of where all of the objects are located in reference to the room. Waller and Hodgson (2006) hypothesized that egocentric pointing and judgment of relative direction would remain the same after disorientation if only an egocentric system was responsible for learning. However, Waller and Hodgson (2006) found that the judgment of relative direction decreased after disorientation, suggesting that both egocentric and allocentric views are used to learn spatial locations.

Spatial Pattern Learning

Evidence has been found to support both the dual process learning system and the unitary associate-based learning system (Burgess, 2006; Chamizo, 2003); however these learning systems cannot explain a type of spatial learning that involves neither discrete

landmarks nor environmental geometry (Brown & Terrinoni, 1996). First investigated by Brown and Terrinoni (1996), a series of experiments with rats were used to study spatial learning in the absence of landmarks and environmental geometry. They designed a “pole box” (see Figure 1) that consisted of an enclosure that contained an array of poles in a consistent matrix (4 x 5 and 5 x 5 arrays) (Brown & Terrinoni, 1996). This pole box did not contain any significant landmarks or environmental geometry. More specifically, the environmental geometry was not congruent with the location of the goals and the discrete visual landmarks were absent because all of the poles (including the goal locations) were the same dimensions and color. Instead, the baited poles (i.e., goal locations) were arranged in different spatial patterns within the array. These poles were baited by hiding food in wells on top of the vertical poles. The baited poles were arranged in a straight line for the first condition, a square for the second condition, and a checkerboard for the third condition (Brown & Terrinoni, 1996).

To determine the extent to which search behavior came under control of a spatial pattern, the number of searches and the direction of search following the discovery of each goal was analyzed. This analysis of search after the discovery of a goal location was termed search transition. More specifically, search transition refers to the mean errors to locate the next goal following the discovery of the previous goal location. The logic was that if the rat had learned the spatial relationship among the goal locations, then the number of searches should successively decrease. Moreover, the direction of search should mirror the spatial arrangement of the baited poles. More specifically, if the baited poles were arranged in a line, then the rats should show an increased tendency to search

adjacent poles following each goal found whereas if the baited poles were arranged in a checkerboard, the rat should show an increased tendency to search diagonally. Brown and Terrinoni (1996) found that the rat's search did seem to mirror the spatial pattern in which the baited poles were arranged and the expected move type (i.e. adjacent for line, diagonal for checkerboard) increased after each goal was found. It can be argued that these results were due to conditioning because each baited pole could have reinforced the rat's next move. However if this were true, then the rats would have performed closer to chance due to the discovery of un-baited poles within the experiment, ultimately leading to a balance between extinction and reacquisition within each trial (Brown & Terrinoni, 1996).

Brown and Terrinoni (1996) argued for a separate learning system that controls spatial learning in the absence of landmarks and environmental geometry distinct from both the unitary associative-based learning system and the dual process learning system. Because this experiment was void of both discrete landmarks and environmental geometry, the spatial relationships between the goal locations were the only cues available to locate the goal locations. Furthermore, the search transition of the rats began to mirror the spatial pattern of the goal locations without the assistance of these cues (Brown & Terrinoni, 1996). More specifically, the mean errors to locate the second goal location followed by the discovery of the first goal location (i.e., first to second), the mean errors to locate the third goal location followed by the discovery of the second goal location (i.e., second to third) and the mean errors to locate the fourth goal location followed by the discovery of the third goal location (i.e., third to fourth) showed

reductions across trials. The overall findings from this study suggest that there is a learning system separate and distinct from previous models of spatial learning (i.e., unitary associative-based system and the dual process system) that does not use landmarks or environmental geometry that is responsible for this phenomenon.

To explain the phenomenon of spatial learning in the absence of both landmarks and environmental cues, an additional type of spatial learning has been proposed. This spatial learning, termed spatial pattern learning, is based on geometric information rather than discrete visual landmarks or environmental geometry (Brown & Terrinoni, 1996). Spatial pattern learning involves the use of relationships of locations in an environment with relation to each other (Sturz et al., 2010). More specifically, spatial pattern learning is the ability to learn the spatial relations among locations.

However, it can be argued that the goal locations can be viewed as landmarks and therefore, the unitary associative-based learning system may also account for this learning. However, if the unitary associative-based learning system is responsible for learning within this environment, then cue-competition, such as blocking and overshadowing should be present. That is, cue-competition between the previously learned relationships of goal locations and landmarks and the new relationships of goal locations and landmarks should be found if the unitary associative-based learning system is responsible for this type of learning because landmark learning has been found to be susceptible to both blocking and overshadowing (Miller & Shettleworth, 2007). To test this, Brown et al. (2002) and more recently Sturz et al. (2009) conducted a series of experiments.

Brown et al. (2002) conducted a series of experiments to examine whether competing cues affect spatial pattern learning in rats. Initially, rats were either trained with extra visual stimuli present in the environment (i.e., different colored baiting poles) or with all of the baiting poles being the same color. Subsequently, all rats were later tested with all of the baiting poles being the same color. The results revealed that all of the rats were able to learn the configuration in both the training and the testing trials, even when multiple cues (i.e., visual stimuli) were present in the training sessions (Brown et al., 2002). This experiment was later replicated in humans, both in a virtual and in a real-world environment (Sturz, et al., 2009). Humans were trained and tested in a similar apparatus used in the Brown et al. (2002) study, in which visual stimuli were either present or not present during training and visual stimuli were not present during testing. The human participants, both in the real-world and the virtual environment were able to learn the configuration, even when the visual stimuli were present during the training sessions. This evidence shows that spatial pattern learning is not affected by cue-competition between the previously learned relationships of goal locations and landmarks and the new relationships of goal locations and landmarks, unlike spatial learning using discrete visual landmarks in landmark-goal learning (Brown et al., 2002; Sturz, et al., 2009).

More recently Sturz et al. (2009, 2010) tested humans in both real-world and virtual environments in which visual cues were paired with the correct goal locations. That is, the goal locations were paired with different visual stimulus than the non-goal locations (i.e. goal locations were red, non-goal locations were white). The unitary

associative-based learning model predicted that those trained in the presence of visual cues should perform worse than those trained in the absence of cues because the presence of extra information would cause cue-competition between the previously learned relationships of goal locations and landmarks and the new relationships of goal locations and landmarks. Additionally, the dual process learning model suggested that the participants should not be able to learn in these environments because of the lack of congruency between the environmental geometry and the location of the goal locations. The results showed that the human participants were able to learn the configuration of the goal locations while also learning spatial relationships between the discrete visual landmarks and the goal configuration (Sturz et al., 2009). In addition, Sturz et al. (2009) found evidence of facilitation of learning when a landmark (i.e. red bin in the middle of a diamond goal pattern) was paired with the goal locations. That is, the participants were able to learn the goal configuration faster when a landmark was paired with the goal locations. Evidence for facilitation was found for both a square pattern and a diamond pattern in both the real-world and virtual environments, replicating the findings of Brown and Terrinoni (1996) study. These results suggest that spatial pattern learning is not only distinct in that it is not affected by cue competition, but spatial pattern learning may also be sensitive to other cues.

The facilitation of learning does not seem to apply to all cues however. Auditory cues were tested to see if facilitation of learning could be found (Sturz, Kilday, Bodily, & Kelly, 2012). In this experiment, each goal location was designated a discrete auditory cue different from one another, whereas all of the non-goal locations maintained the same

auditory cue. Auditory cues did not facilitate or hinder learning when auditory cues were matched with the correct goal locations. In addition, the auditory cues did not obstruct learning of the goal locations (Sturz et al., 2012). One possible explanation for these results is that the auditory cues were transient in nature, rather than visual cues which were fixed (Sturz et al., 2009, 2010). More specifically, each auditory cue was only present upon the discovery of a goal, whereas the visual cues were always present in the environment. The lack of evidence of facilitation of learning in this experiment suggests that the learning system responsible for spatial pattern learning may only be sensitive to visual cues or that there was something different about the auditory cues, such as that visual cues reveal themselves through space (always present) whereas auditory cues reveal themselves through time (conditionally present). Upon the assumption that spatial pattern learning is controlled by a separate learning system, it appears that spatial pattern learning does not use auditory cues. As a result, it appears that spatial pattern learning may only use visual cues, and therefore these cues need to be studied further.



Figure 1. Photograph of 5 X 5 Pole Box apparatus similar to that used in the Brown and Terrinoni (1996) study (from Brown, 2006).

CHAPTER 3

SUMMARY AND OVERVIEW OF CURRENT STUDY

Collectively, extant results suggest that spatial pattern learning is a distinct form of learning that is both distinct and separate from both landmark and environmental geometry spatial learning. However, to date only visual cues have been shown to facilitate spatial pattern learning (Brown & Terrinoni, 1996; Brown et al., 2002; Sturz et al., 2009, 2010, 2012). To further test if spatial pattern learning is controlled by a distinct learning system that is separate from other models of spatial learning (i.e., unitary associative-based learning system and the dual process learning system) and the extent to which such a pattern learning system relies on visual pattern information, we tested two groups. The first group experienced the presence of visual stimuli that was in the same arrangement as the unmarked goal locations (i.e. Visual Pattern group) and the second group experienced the presence of visual stimuli in random locations while the goal locations remained in a fixed pattern (Visual Random group). For both groups, the visual stimuli were not consistent with the goal locations.

Hypotheses

If there is a system dedicated to processing visual pattern information, then the Visual Pattern group should perform better than the Visual Random group. Specifically, if participants in the Visual Pattern group exhibit fewer errors to complete a trial across trials than those in the Visual Random group, then it can be argued that the presence of a visual pattern consistent with the pattern of the goal locations has facilitated learning and would suggest that spatial pattern learning is processed by a distinct learning system (see

Table 1). Secondly, if the participants in the Visual Pattern group show a faster decrease in errors to complete a trial than those in the Visual Random group, then it can also be argued that the presence of a visual pattern consistent with the pattern of the goal locations has facilitated learning (See Table 1). Furthermore, if the participants in the Visual Pattern group show a faster decrease in adjacent and other moves while showing an increase in diagonal moves than those in the Visual Random group, then it can also be argued that spatial learning was facilitated by the presence of the visual pattern because the goals are configured in a diamond pattern, which would lead to more diagonal moves after the discovery of a goal than adjacent moves (See Table 1). Lastly, if errors within each trial (search transition) are found to decrease faster in the Visual Pattern group compared to the Visual Random group, then evidence for facilitation of spatial pattern learning is supported (See Table 1). These results would suggest that a separate and distinct system is responsible for spatial pattern learning for two reasons. First, the unitary associative-based learning system would predict that learning would not occur in this environment for both groups due to the lack of discrete landmarks that are congruent with the goal locations. Secondly, the dual process learning system would predict that learning would not occur in this environment for both groups as the environmental geometry and the discrete landmarks are not congruent with the goal locations. Alternatively, if both the Visual Pattern and the Visual Random groups do not differ in results, then there would be a lack of evidence of facilitation of spatial pattern learning and a lack of support for the distinctness of a spatial pattern learning system (See Table 2).

Table 1. *Predictions for Each Group if the Presence of the Visual Pattern Facilitates Spatial Pattern Learning.*

	Mean Number of Choices to Complete a Trial	Mean Number of Errors to Find a Goal Location	Proportion of Adjacent Moves Following the Discovery of a Goal Location	Proportion of Other Moves Following the Discovery of a Goal Location	Proportion of Diagonal Moves Following the Discovery of a Goal Location
Visual Pattern	Few choices and a fast decrease in the amount of choices made across trials.	Few errors and a fast decrease in the amount of errors made across trials.	Small proportion of adjacent moves and a fast decrease of adjacent moves across trials.	Small proportion of other moves and a fast decrease of other moves across trials.	High proportion of diagonal moves and a fast increase of diagonal moves across trials.
Visual Random	More choices and slower decrease in the amount of choices made across trials compared to the Visual Pattern group.	More errors and slower decrease in the amount of errors made across trials compared to the Visual Pattern group.	Higher proportion of adjacent moves and slower decrease of adjacent moves across trials compared to the Visual Pattern group.	Higher proportion of other moves and slower decrease of other moves across trials compared to the Visual Pattern group.	Lower proportion of diagonal moves and a slow increase of diagonal moves across trials compared to the Visual Pattern group.

Table 2. *Predictions for Each Group if the Presence of a Spatial Pattern does not Facilitate Spatial Pattern Learning.*

	Mean Number of Choices to Complete a Trial	Mean Number of Errors to Find a Goal Location	Proportion of Adjacent Moves Following the Discovery of a Goal Location	Proportion of Other Moves Following the Discovery of a Goal Location	Proportion of Diagonal Moves Following the Discovery of a Goal Location
Visual Pattern	Moderate amount of choices and a slight decrease in the amount of choices made across trials (same as Visual Random group).	Moderate amount of errors and a slight decrease in the amount of errors made across trials (same as Visual Random group).	Moderate proportion of adjacent moves and a slight decrease of adjacent moves across trials (same as Visual Random group).	Moderate proportion of other moves and a slight decrease of other moves across trials (same as Visual Random group).	Moderate proportion of diagonal moves and a slight increase of diagonal moves across trials (same as Visual Random group).
Visual Random	Moderate amount of choices and a slight decrease in the amount of choices made across trials (same as Visual Pattern group).	Moderate amount of errors and a slight decrease in the amount of errors made across trials (same as Visual Pattern group).	Moderate proportion of adjacent moves and a slight decrease of adjacent moves across trials (same as Visual Pattern group).	Moderate proportion of other moves and a slight decrease of other moves across trials (same as Visual Pattern group).	Moderate proportion of diagonal moves and a slight increase of diagonal moves across trials (same as Visual Pattern group).

CHAPTER 4

METHOD

Participants

Forty eight Georgia Southern University undergraduate students (24 male and 24 female) participated in the experiment. The participants received extra class credit for their participation or participated as part of a course requirement.

Apparatus

An interactive 3-D virtual environment was constructed using the Valve Hammer Editor and was run on the Half-Life Team Fortress Classic platform (see Figure 2). The interface was comprised of a personal computer, 21-inch flat-screen liquid crystal display (LCD) monitor (1650 x 1050 pixels), a Logitech Dual Action gamepad, and speakers. A first person perspective of the virtual environment was provided by the monitor (see Figure 2). Navigation of the virtual environment was controlled using the video game controller. Speakers emitted auditory feedback. All of the experimental events were recorded using the Half-Life Dedicated Server on an identical personal computer.

Stimuli

The dimensions of the virtual environment were similar to those used in the studies conducted by Sturz et al. (2009, 2010, 2011a, 2011b). The dimensions are length x width x height and are measured in virtual units (vu) in which 1 vu is equal to about 2.54 cm. The virtual environment (1050 x 980 x 416 vu) contained 25 raised bins (86 x 86 x 38 vu) arranged in a 5 x 5 matrix (see Figure 3). All but four of the bins were of the same color (white). The remaining four bins were a different distinct color (red). The

room was illuminated by a light source centered 64 vu below the ceiling. All of the walls were black with the exception of the wall opposite the start location which was brown (see Figure 2).

Procedures

The procedure that was used for the spatial pattern learning task is similar to the procedure used in Sturz et al. (2010, 2011a). There were 30 trials in which the participants were given 50 minutes to complete. Each trial consisted of a search task in which the participants searched for four unmarked goal locations. To complete a trial, the participants needed to find all four goal locations to be automatically transported to the next trial (i.e. next virtual room). If the participants exceeded the allotted time, they were asked to stop and their data were not included in analysis. The starting location was always in the middle of the southern wall with the participant's view facing the middle of the northern wall (see Figures 1 and 2). The participants navigated through the virtual room using the video game controller left analog stick: \uparrow (forward), \downarrow (backward), \leftarrow (turn left), and \rightarrow (turn right). Therefore, as the participants turned in the environment using the joystick, the view turned in the same direction. The view could be rotated at 360° by using the left or right function of the joystick to rotate the character at 360° . Jumping was achieved by clicking the "2" button on the controller. To jump into a bin, participants needed to simultaneously move forward and jump towards the intended bin. Auditory feedback indicated movement (footstep sounds), jumping actions ("huh" sound), correct bin choice ("ding" sound), and incorrect choice ("buzzer" sound).

Participants were randomly assigned to two groups: Visual Pattern and Visual Random. For both groups, the participants were instructed to find four goal locations (bins). After locating the fourth goal location, the game transported their character to the next virtual room. The correct goal locations were unmarked bins that were always arranged in a diamond pattern (see Figure 3). This diamond pattern was randomly moved from trial-to-trial but the goal locations always maintained the same spatial relationship (i.e. in the shape of a diamond). In the Visual Pattern group, four red bins were also arranged in a diamond pattern and were not consistently related to the four goal locations (see Figure 3). However, these red bins overlapped with the goal locations for a total of 31 times with two of the trials having the four red bins overlap the four goal locations. These red bins differed in location from trial-to-trial and always maintained the same spatial relationship to each other (i.e. in the shape of a diamond). In the Visual Random group, the red bins were arranged in a random configuration that changed from trial-to-trial and were also not consistently related to the four goal locations or to each other (see Figure 3). However, these red bins overlapped with the goal locations for a total of 17 times, in which no trial had all four red bins overlap all four goal locations.

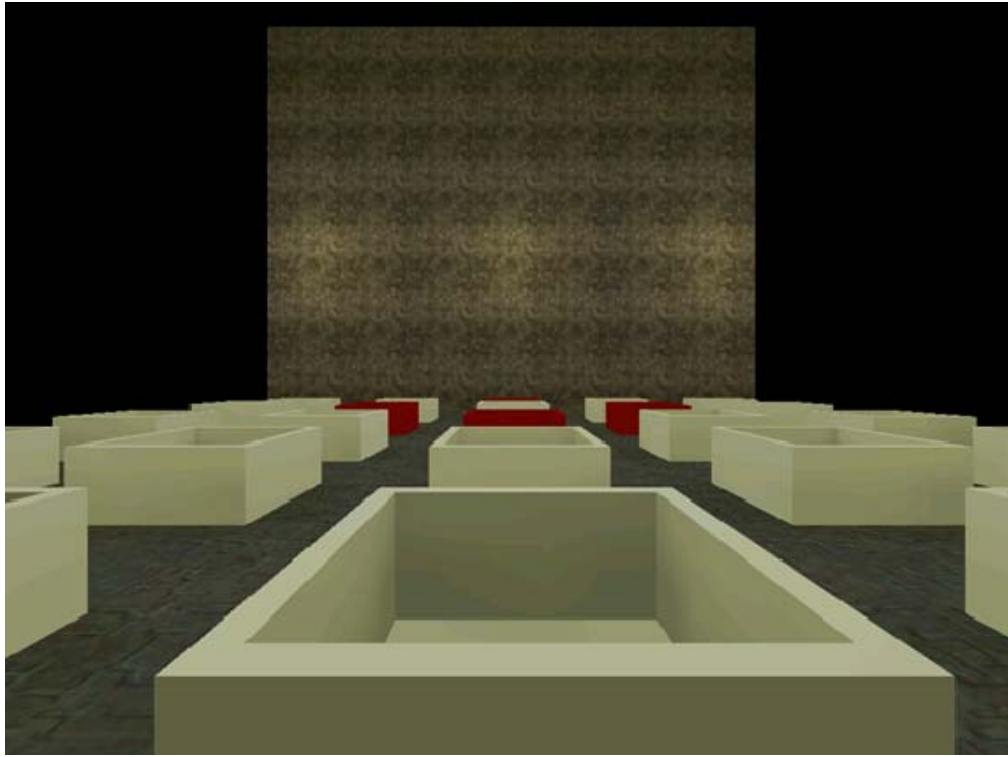


Figure 2. The view from the starting point in the virtual environment in first person perspective for the Visual Pattern group.

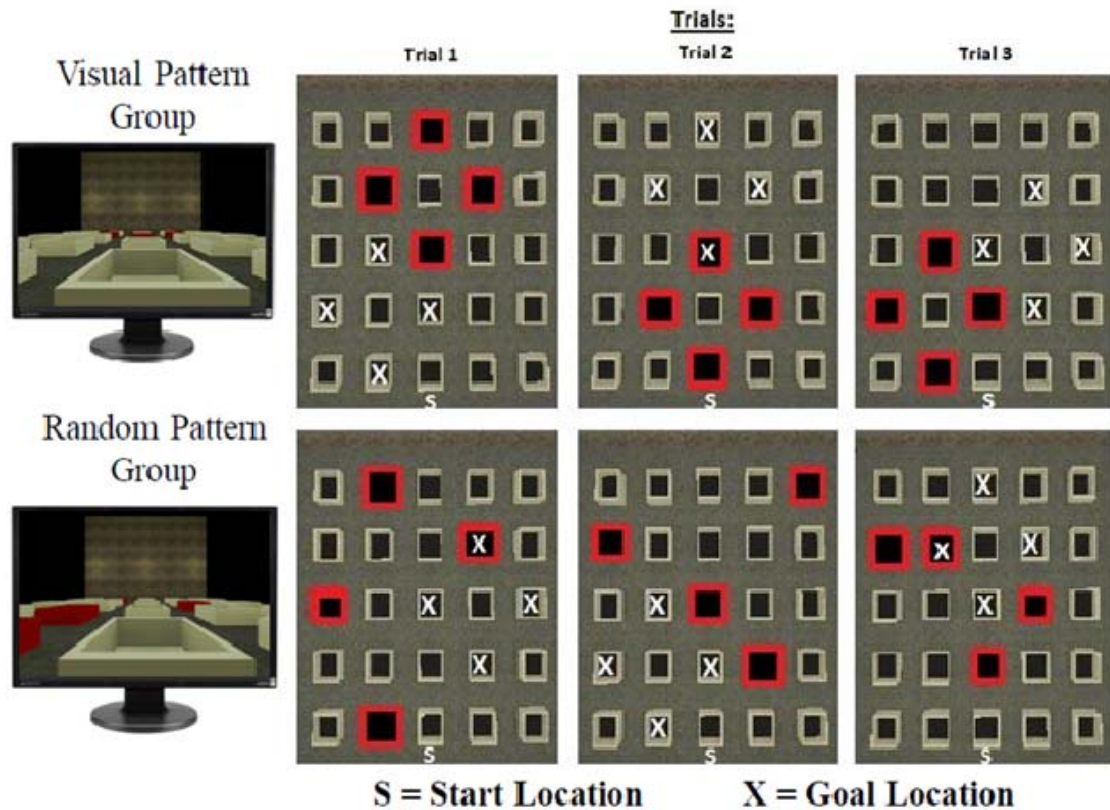


Figure 3. The above Figure is an overhead view of the search space with an example of the virtual environment for both groups on the right. The top three diagrams represent the Visual Pattern group whereas the bottom three diagrams represent the Visual Random group. Red squares represent the visual stimuli, white “X’s” represent a goal location, and white “S’s” represent the start location.

CHAPTER 5

RESULTS

Three types of data were analyzed: mean errors to complete a trial across six five-trial trial blocks, search transition across six five-trial trial blocks, and percentage of move type (i.e., adjacent, diagonal, and other) across six five-trial trial blocks. It was hypothesized that if spatial pattern learning uses visual stimuli to enhance learning, then the Visual Pattern group would show a faster decrease in the mean errors to complete a trial and overall fewer mean errors to complete a trial across trials compared to the Visual Random group. It was also hypothesized that if spatial pattern learning uses visual stimuli to enhance learning, then the Visual Pattern group would show a faster decrease in the mean errors during the search for a goal location within each trial (search transition) and overall fewer errors during the search for a goal location across trials compared to the Visual Random group. It was also hypothesized that if spatial pattern learning uses visual stimuli to enhance learning, then the Visual Pattern group would show a faster increase of the percentage of diagonal and decrease of adjacent and other moves and overall more diagonal moves and less adjacent and other moves across trials compared to the Visual Random group.

Alternatively, it was hypothesized that if spatial pattern learning does not use visual stimuli, then both the Visual Pattern group and the Visual Random group would perform the same in all analyses across trials. Lastly, the unitary associative-based learning system or the dual process learning system would not predict learning in both of these environments. This is because the visual landmarks and the environmental

geometry are not consistently paired with the goal locations, and therefore do not predict the location of the goal within the environment.

Hypotheses Testing

Mean errors to complete a trial. The mean errors made to complete a trial (i.e., find all four goal locations) across six five-trial trial blocks were analyzed. Mean errors to complete a trial were investigated because upon learning the relationship of the goal locations, one should make fewer errors. That is, learning about the spatial relations among locations across successive trial blocks should result in a decrease in the number of errors to complete a trial (i.e., to find all four goal locations).

A 2 x 6 mixed Analysis of Variance (ANOVA) on the mean errors to complete a trial with Group (Visual Pattern, Visual Random) and Trial Block (1-6) as factors was conducted. Results showed that there was a main effect of Group, $F(1, 46) = 5.64, p < .05$ with participants in the Visual Pattern group ($M = 10.22, SEM = .60$) making fewer errors to complete a trial than participants in the Visual Random group ($M = 13.76, SEM = .58$) (see Figure 4). The results also showed a main effect for Trial Block, $F(5, 230) = 26.30, p < .05$. Post hoc tests on the Block factor revealed that Block 1 ($M = 17.13, SEM = 1.00$) differed from Block 2 ($M = 14.35, SEM = .99$), Block 3 ($M = 11.83, SEM = 1.08$), Block 4 ($M = 10.07, SEM = .98$), Block 5 ($M = 9.23, SEM = .85$), and Block 6 ($M = 9.34, SEM = .88$) ($ps < .01$); Block 2 differed from Block 3, Block 4, Block 5, and Block 6 ($ps < .01$); and Block 3 differed from Block 4, Block 5, and Block 6 ($ps < .01$). Block 4 did not differ from Blocks 5 and 6 ($ps > .05$). Block 5 did not differ from Block

6 ($ps > .05$)(see Figure 4). The Group x Trial Block interaction was not significant, $F(5, 230) = 2.05, p > .05$.

Search transition. Search transition, defined as the mean errors to locate a goal following the discovery of a goal location across six five-trial trial blocks was analyzed to investigate if learning has occurred. More specifically, the mean errors to locate the second goal location followed by the discovery of the first goal location (i.e. first to second) and the mean errors to locate the third goal location followed by the discovery of the second goal location (i.e. second to third) was investigated. The mean errors that are recorded between the start of the trial and the discovery of the first goal were not analyzed. This is because the discovery of the first goal is based on trial-and-error learning, and therefore does not provide information about learning the spatial relations among locations. Additionally the discovery of each successive goal will reduce uncertainty about the location of the next goal, and perfect spatial pattern learning would provide unambiguous information about the location of the last goal. Therefore, the mean errors recorded between the discovery of the third and the fourth goals was not investigated as this analysis should not be sensitive between the groups

The search transition of each participant was investigated because upon learning the relationship of the goal locations, one should make fewer errors after the discovery of each goal location from trial to trial. That is, learning of the spatial relations among locations should result in fewer errors to locate the next goal location once a goal location has been discovered. More specifically, learning the spatial relations among locations reduces the potential locations of the remaining goal locations.

A 2 x 2 x 6 mixed ANOVA on errors to locate a goal following the discovery of a goal with Group (Visual Pattern, Visual Random), Transition Type (1st to 2nd, 2nd to 3rd), and Trial Block (1-6) as factors was conducted. Results showed that there was a main effect of Group, $F(1, 46) = 7.13, p < .05$ with participants in the Visual Pattern group ($M = 1.83, SEM = .12$) making fewer errors after the discovery of a goal location than participants in the Visual Random group ($M = 2.78, SD = .13$) (see Figures 5 and 6). Results also showed that there was a main effect of Transition Type, $F(1, 46) = 20.51, p < .05$ with more errors between the discovery of the first and second goals ($M = 2.83, SEM = .14$) than between the discovery of the second and third goals ($M = 1.78, SEM = .11$) (see Figures 5 and 6). The results also showed a main effect for Trial Block, $F(5, 230) = 14.48, p < .05$. Post hoc tests on the Block factor revealed that Block 1 ($M = 3.43, SEM = .23$) differed from Block 2 ($M = 2.55, SEM = .22$), Block 3 ($M = 1.94, SEM = .19$), Block 4 ($M = 2.07, SEM = .23$), Block 5 ($M = 2.00, SEM = .21$), and Block 6 ($M = 1.86, SEM = .22$) ($ps < .001$); Block 2 differed from Block 3, Block 5, and Block 6 ($ps < .05$); and Block 3 did not differ from Block 4, Block 5, and Block 6 ($ps > .05$). Block 4 did not differ from Blocks 5 or 6. Block 5 did not differ from Block 6 ($ps > .05$) (see Figures 5 and 6). The Group x Trial Block interaction was not significant, $F(5, 230) = 1.73, p > .05$. The Group x Transition Type interaction was not significant, $F(1, 46) = .34, p > .05$. The Transition Type x Trial Block interaction was not significant, $F(5, 230) = 1.98, p > .05$. The Group x Transition Type x Trial Block interaction was not significant, $F(5, 230) = .55, p > .05$.

Move type. Move type was investigated because the goal locations were arranged in a diamond pattern. Therefore, if learning has occurred, adjacent moves after the discovery of a goal location should decrease across trial blocks and diagonal moves after the discovery of a goal location should increase across trial blocks due to the diagonal relationships that the goal locations have with each other

Adjacent moves. The percentage of adjacent moves following the discovery of a goal location across six five-trial trial blocks was analyzed to investigate if learning had occurred. A 2 x 6 mixed ANOVA on percentage of adjacent moves following the discovery of a goal location with Group (Visual Pattern, Visual Random), and Trial Block (1-6) as factors was conducted. Results showed that there was a main effect of Group, $F(1, 46) = 6.03, p < .05$ with participants in the Visual Pattern group ($M = .47, SEM = .04$) making less adjacent moves after discovering a goal location than participants in the Visual Random group ($M = .56, SEM = .04$) (see Figure 7). The results also showed a main effect for Trial Block, $F(5, 230) = 6.95, p < .05$. Post hoc tests on the Block factor revealed that Block 1 ($M = .62, SEM = .04$) differed from Block 3 ($M = .51, SEM = .07$), Block 4 ($M = .47, SEM = .07$), Block 5 ($M = .47, SEM = .07$), and Block 6 ($M = .48, SEM = .07$) ($ps < .05$); Block 2 ($M = .58, SEM = .06$) differed from Block 3, Block 4, Block 5, and Block 6 ($ps < .05$); and Block 3 differed from Block 4, Block 5, and Block 6 ($ps < .05$). Block 4 did not differ from Blocks 5 and 6 ($ps > .05$). Block 5 did not differ from Block 6 ($ps > .05$) (see Figure 7). The Group x Trial Block interaction was not significant, $F(5, 230) = .02, p > .05$.

Diagonal moves. The percentage of diagonal moves following the discovery of a goal location across six five-trial trial blocks was analyzed to investigate if learning had occurred. A 2 x 6 mixed ANOVA on percentage of diagonal moves after the discovery of a goal location with Group (Visual Pattern, Visual Random), and Trial Block (1-6) as factors was conducted. Results showed that there was a main effect of Group, $F(1, 46) = 6.66, p < .05$ with participants in the Visual Pattern group ($M = .53, SD = .05$) making more diagonal moves after discovering a goal location than participants in the Visual Random group ($M = .26, SD = .03$) (see Figure 8). The results also showed a main effect for Trial Block, $F(5, 230) = 23.42, p < .05$. Post hoc tests on the Block factor revealed that Block 1 ($M = .18, SEM = .03$) differed from Block 2 ($M = .32, SEM = .05$), Block 3 ($M = .41, SEM = .06$), Block 4 ($M = .49, SEM = .07$), Block 5 ($M = .49, SEM = .07$), and Block 6 ($M = .49, SEM = .07$) ($ps < .001$); Block 2 differed from Block 3, Block 4, Block 5, and Block 6 ($ps < .01$); and Block 3 differed from Block 4, Block 5, and Block 6 ($ps < .01$). Block 4 did not differ from Blocks 5 and 6 ($ps > .05$). Block 5 did not differ from Block 6 ($ps > .05$) (see Figure 8). The group x Trial Block interaction was not significant, $F(5, 230) = 1.79, p > .05$.

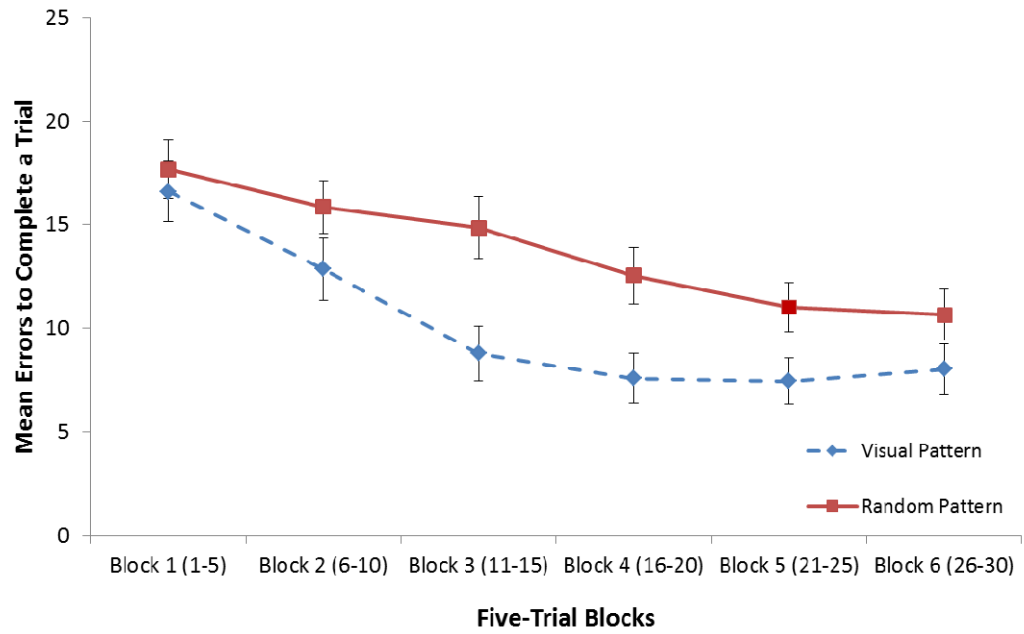


Figure 4. Mean number of errors to complete a trial, plotted by six five-trial trial blocks for each group. Error bars represent standard errors of the means.

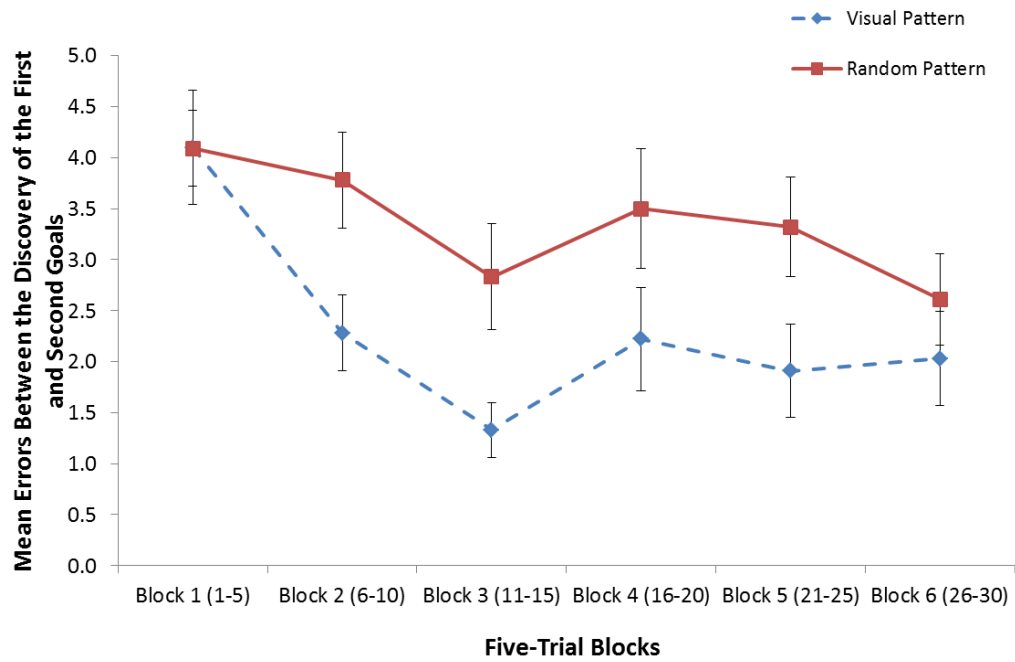


Figure 5. Mean number of errors for locating the second goal after the discovery of the first goal (i.e., search transition), plotted by six five-trial trial blocks for each group. Error bars represent standard errors of the means.

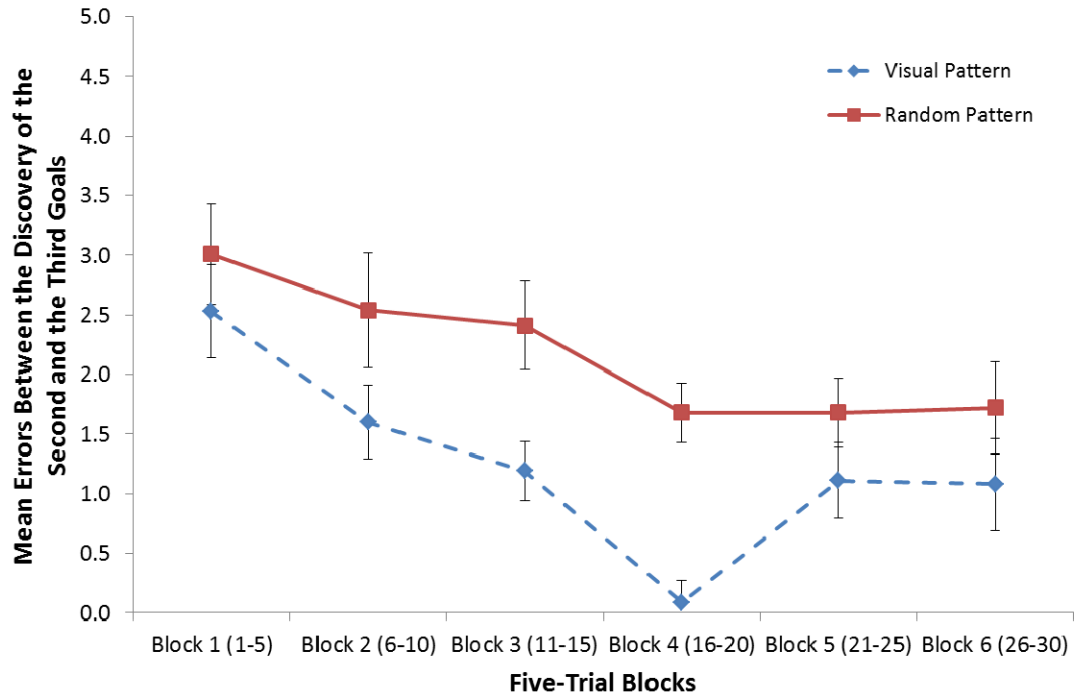


Figure 6. Mean number of errors for locating the third goal after the discovery of the second goal (i.e., search transition), plotted by six five-trial trial blocks for each group. Error bars represent standard errors of the means.

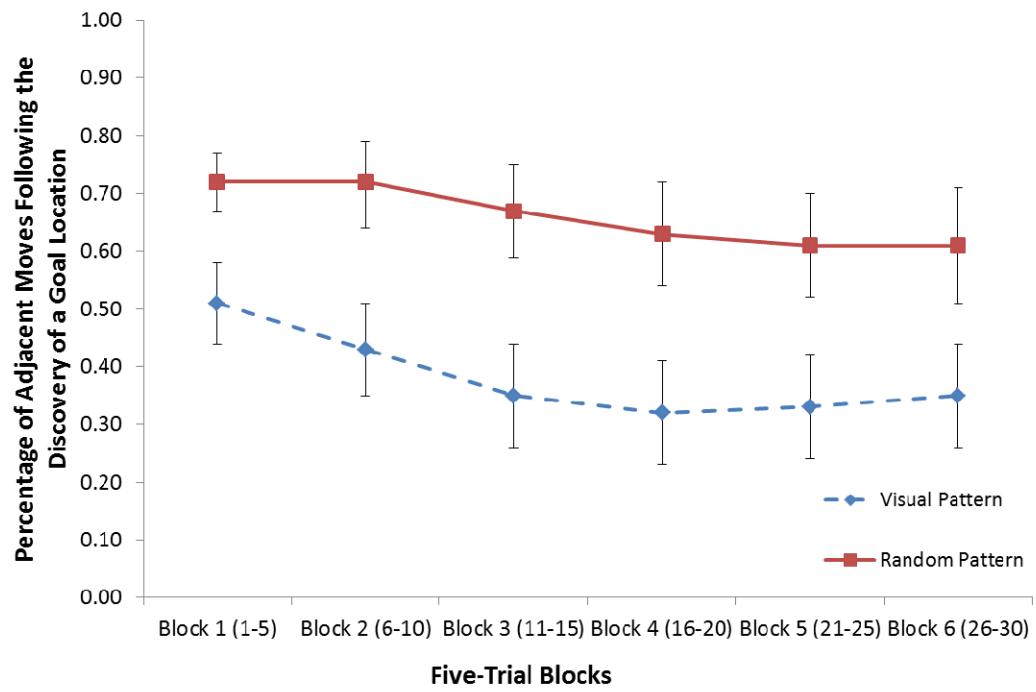


Figure 7. Mean percentage of adjacent moves following the discovery of a goal location, plotted by six five-trial trial blocks for each group. Error bars represent standard errors of the means.

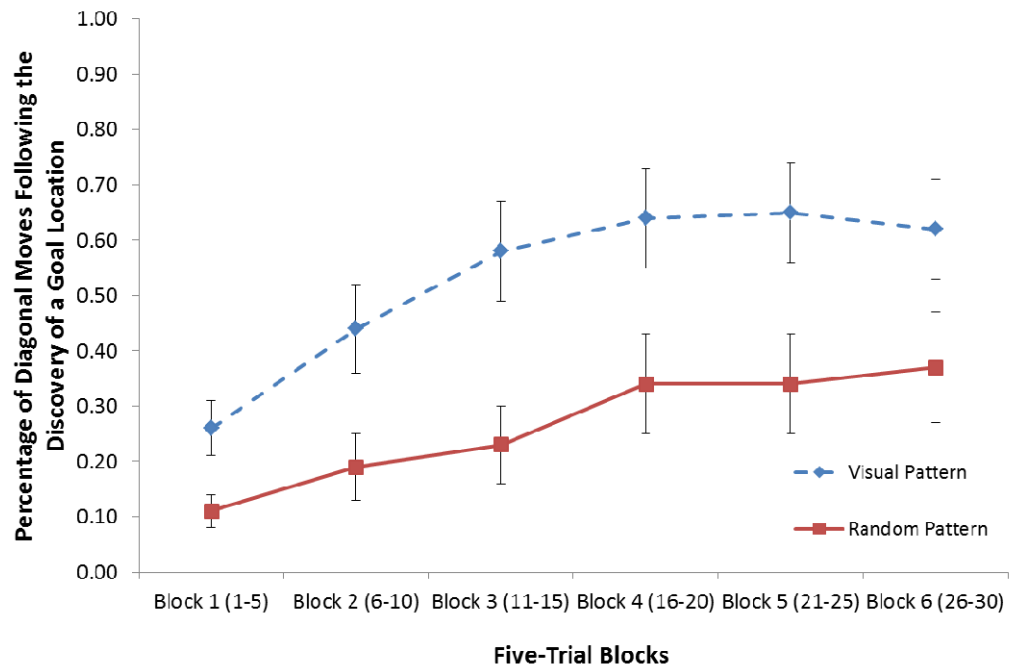


Figure 8. Mean percentage of diagonal moves following the discovery of a goal location, plotted by six five-trial trial blocks for each group. Error bars represent standard errors of the means.

CHAPTER 5

DISCUSSION

To investigate if spatial pattern learning is controlled by a separate and distinct learning system that processes visual pattern information, two groups (Visual Pattern group, Visual Random group) of twenty four participants were asked to find four goal locations in a virtual environment search task. The virtual environment for both groups contained twenty five raised bins, four of which were colored red and twenty one were colored white. Four bins within the environment were the goal locations in which the participants were instructed to find. These goal locations always remained in a diamond pattern, and were randomly moved around the search space from trial-to-trial. The four red bins also maintained a diamond pattern for Visual Pattern group, in which this visual pattern was randomly moved around the search space from trial-to-trial and was not congruent with the goal locations. The red bins for the Visual Random group were randomly spaced in the search space and were randomly moved around the search space from trial-to-trial.

The results found that all of the participants were able to learn the spatial pattern of the goal locations. The results also found that the participants in the Visual Pattern group learned the spatial pattern faster than those in the Visual Random group and that the Visual Pattern group performed better overall compared to the Visual Random group. More specifically, the Visual Pattern group had fewer errors to complete a trial, fewer errors within the search transition of each trial, and made more diagonal moves and less adjacent moves after discovering a goal location than the Visual Random group. The

Visual Pattern group was also found to have a faster decrease in errors to complete a trial across trials, faster decrease in errors within the search transition of each trial across trials, and a faster increase in diagonal moves and faster decrease in adjacent moves across trials.

It was hypothesized that if spatial pattern learning uses visual stimuli, then the Visual Pattern group should show a faster decrease in errors and overall fewer errors both within a trial (search transition) and to complete a trial. In addition, it was also hypothesized that if spatial pattern learning uses visual stimuli, then the participants in the Visual Pattern group should show a faster increase in diagonal moves and overall higher percentage of diagonal moves compared to the Visual Random group. However, it was also hypothesized that if spatial pattern learning does not use visual stimuli, then both the Visual Pattern group and the Visual Random group would perform the same in all analyses across trials. Lastly, the unitary associative-based learning system or the dual process learning system would not predict learning in both of these environments. This is because the visual landmarks and the environmental geometry are not consistently paired with the goal locations, and therefore do not predict the location of the goal within the environment.

In line with the hypotheses pertaining to the use of visual stimuli, the results of the study showed that the presence of consistent (but not coincident) visual spatial pattern enhanced learning within the environment. This was shown both within a trial and across trials. The participants who experienced a consistent (but not coincident) visual spatial pattern in the environment made significantly fewer errors than those who experienced

random visual pattern. Furthermore, those in the Visual Pattern condition made significantly fewer adjacent moves and significantly more diagonal moves than those in the Visual Random condition. In addition, the participants in the Visual Pattern condition learned the relations among locations faster than those who were in the Visual Random condition.

These results provide further evidence for Brown and Terrinoni's (1996) original suggestion that spatial pattern learning is processed by a separate and distinct system from the unitary associative-based account and the dual process account for spatial learning. This is because both the unitary associative-based learning system and the dual process learning system would not predict learning in this environment in which discrete visual landmarks were absent and the environmental geometry was not paired with the goal locations. More specifically, the unitary associative-based learning system utilizes all of the discrete landmarks within an environment to both orient and locate goal locations (Chamizo, 2003). In this experiment, discrete visual landmarks were absent from the environment, and therefore could not be used to discover the goal locations. It can be argued that the goal locations act as discrete landmarks upon discovery. However, landmark learning has been found to be susceptible to Pavlovian phenomena (i.e., blocking and overshadowing) whereas spatial pattern learning has not been found to be susceptible to Pavlovian phenomena (Brown et al., 2002; Sturz, et al., 2009, 2010). Therefore, it can be argued that the goal locations are not being used as discrete landmarks. As a result, these findings suggest that the unitary associative-based learning

system cannot explain learning in this environment due to the lack of these discrete landmarks.

In addition, it can also be argued that the dual process learning system cannot explain learning in this environment. The dual process learning system uses both discrete landmarks and environmental geometry to both orient and locate a goal within an environment (Burgess, 2006). In this experiment, the environmental geometry within each trial does not coincide with the goal locations. More specifically, the environmental geometry cannot predict where the goal locations are in the environment and therefore cannot be used to find the goal locations. Furthermore, the environment is void of discrete landmarks that would predict where the goal locations are within the environment. Therefore, without these two sources of information, the dual process model would suggest that learning should not occur in the environment (Burgess, 2006). However, learning occurred for both conditions, and therefore the dual process model cannot explain the spatial learning that occurred in this environment.

These findings suggest that spatial pattern learning uses visual stimuli to recognize spatial patterns due to the better performance by the participants in the Visual Pattern group compared to those in the Visual Random group. These findings also are consistent with the notion that spatial pattern learning is processed by a distinct learning system, separate from both the unitary associative-based system and the dual process learning system. This is because both the unitary associative-based learning system and the dual process learning system cannot explain both learning, and the group differences found within this environment.

Limitations

There are several limitations to this study. First, the Visual Pattern condition and the Visual Random condition exhibit certain qualities that are different between groups. First, the red bins in the Visual Pattern condition overlap with the goal locations 31 times, in which 2 of the trials all four of the red bins overlap with the goal locations. Whereas the red bins only overlap with the goal locations in the Visual Random condition 17 times, in which all four red bins never overlap all four goal locations in a trial. This is a major difference between both groups. It can be argued that the Visual Pattern group learned to search for the visual pattern due to the higher odds of the red bins being rewarded. However, if this difference trained the participants in the Visual Pattern group to only search for the red bins, then the participants in the Visual Pattern group would elicit more errors than those in the Visual Random group. This is because the red bins only overlapped 31 goal locations out of 120 goal locations, and therefore the participants in the Visual Pattern group would show more errors due to only searching the visual pattern. In addition, since the red bins only overlapped 31 goal locations out of 120 goal locations, one would not see the successful learning in this group due to extinction. Furthermore, it can be argued that the Visual Random condition was trained to avoid the red bins. This may have occurred, however the red bins only overlapped the goal locations 17 times and the participants in this condition learned the spatial pattern as well.

Another limitation that can be found in this experiment can be attributed to the array in which the red bins were arranged. In the Visual Pattern condition, the red bins maintained a diamond pattern, and therefore were consistently arranged in a 3 x 3 array.

Whereas the red bins in the Visual Random condition were randomly arranged in the environment from trial to trial. This means that the red bins in the Visual Random condition were arranged in a 5 x 5 array, in which the red bins can randomly move around in the array. These differences are substantial, however the red bins do not serve as discrete visual landmarks and therefore should not direct search in their location. The ineffectiveness of this difference is illustrated by the learning curves of the Visual Random condition. This is because if the red bins were directing search in their direction, then the participants would learned little about the spatial pattern. However, the Visual Random group did learn the spatial pattern.

Lastly, this experiment only used two conditions to test if spatial pattern learning can be facilitated by visual stimuli. This is a problem for several reasons. First, the diamond patterns may have a distinct effect on spatial pattern learning whereas other patterns may not. Secondly, by only using two groups, it is difficult to tell if facilitation occurred for the Visual Pattern group or if inhibition occurred for the Visual Random group. A group in which all of the bins were the same color would need to be tested to tease out these results. Lastly, the visual stimuli in the Visual Pattern condition were arranged in configurations consistent with the goal configuration. This type of consistency may have a direct effect on how spatial patterns are processed, and therefore needs to be further investigated.

Future Directions

The results suggest that spatial pattern learning uses visual stimuli and is processed by a distinct learning system. However, there are several limitations that need

to be addressed in future research. First, the conditions need to be more comparable in which the red bins are arranged. This can be done by having the red bins overlap the goal locations in an equal ratio between groups and maintaining consistent dimensions of the array in which the red bins are arranged across all conditions. For example, when we used a diamond pattern in the environment in which all the bins were arranged in a 5 x 5 array, the diamond pattern itself only consisted of bins within a 3 x 3 array. However, the random pattern utilized the entire 5 x 5 array. By limiting the random condition to a 3 x 3 array within the 5 x 5 environment, one can make better comparisons between the groups.

Furthermore, different visual patterns and goal location patterns need to be tested as well. Simple patterns such as lines and complex patterns such as corners or outlines of shapes can be tested to further investigate how spatial pattern learning is processed. By using both simple and complex patterns, one can test for limitations for both spatial pattern learning and the visual stimuli used to enhance the learning. In addition, inconsistent patterns should also be tested to investigate if inhibition can occur in this type of learning. This can be achieved by having the visual stimuli in one pattern (i.e., diamond pattern) and the goal location pattern in another formation (i.e., line pattern). By testing for inhibition, one can further test the limits of both spatial pattern learning and the visual stimuli used to enhance the learning.

Summary

The findings suggest that spatial pattern learning uses visual stimuli. Participants who experienced a consistent (but not coincident) visual pattern learned the spatial pattern of the goal locations faster and performed better than those who experienced a

random pattern of visual stimuli which was not consistent nor coincident with the goal locations. These results can be argued as evidence for a separate and distinct learning system responsible for processing spatial pattern information.

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